Urban Stream Structure And Selection Of Structures To Build Habitat To Support Wild Fish Populations

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Abstract

This paper gives a brief overview of the physical impacts of urbanization on streams and examines the selection of in-stream methods, tools, and devices for stabilizing streams and creating habitat to support native fish species. Although the paper discusses salmonid species in the Pacific Northwest in particular, the methodologies and tools employed to evaluate and support fish habitat can be generally applied to streams and watersheds in other regions.

The effects of urbanization, such as decreased pervious area and vegetative cover and increased stormwater runoff and erosion, destabilize watersheds and streambeds and destroy aquatic habitats. Stable stream environments are necessary if biological systems including fish and their supporting food web are to flourish. Changes to urban streams and watersheds may be so significant, however, that decades may pass before they reach stability. Even then, the resulting Astable environment@ might not provide the type of habitat needed to support species from the natural environments.

The evaluation of channel erosion and sedimentation in urban streams provides one measure to assess the relative stability of streams and, thus, their ability to support fish and amphibian species. For most streams, an evaluation of relative streambed stability can be completed through a visual examination of streambed morphology and minimal supporting calculations. Tools for performing these analyses will be presented in this paper.

Rehabilitation of streams in urban and heavily logged watersheds requires establishing a stream structure that will maintain streambed stability and create the different types of habitats needed to support desired fish species. One size or type of in-stream device cannot meet all stabilization and habitat requirements. The selection of devices should correspond to the relative stability of the individual stream reach. Devices for maintaining streambed stability and creating habitat, as well as the procedures for selecting them, will be discussed in this paper.

Introduction

Salmon populations in the Pacific Northwest are dwindling. One significant cause of this reduction in population is the destruction of small stream (1st to 4th order) habitats.

In order to respond to the destruction of fish habitat in small streams, we must have an understanding of watershed processes and natural stream morphology. Although this paper concerns western Washington streams, which are surrounded by heavy forests and fed by rain and groundwater, the general principles for stabilizing streams discussed here can be applied to most natural small stream systems.

Natural Stream Morphology

Streambed gradients gradually decrease from the upper reaches of a watershed to the outlet of a stream because flow rates increase in the lower parts of the watershed (Leopold, Wolman, and Miller, 1964).

The streambed gradients create different types of fish habitat features (Rosgen, 1994). Figure 1 shows the relationship of habitat type to streambed slope in western Washington streams. Pool/drop habitat is dominant in reaches with smaller flows and steeper valley gradients. The pools are formed by large organic debris or rock formations. As the stream flow rates increase, valley gradients tend to decrease and the streams are dominated by pool/riffle habitats.

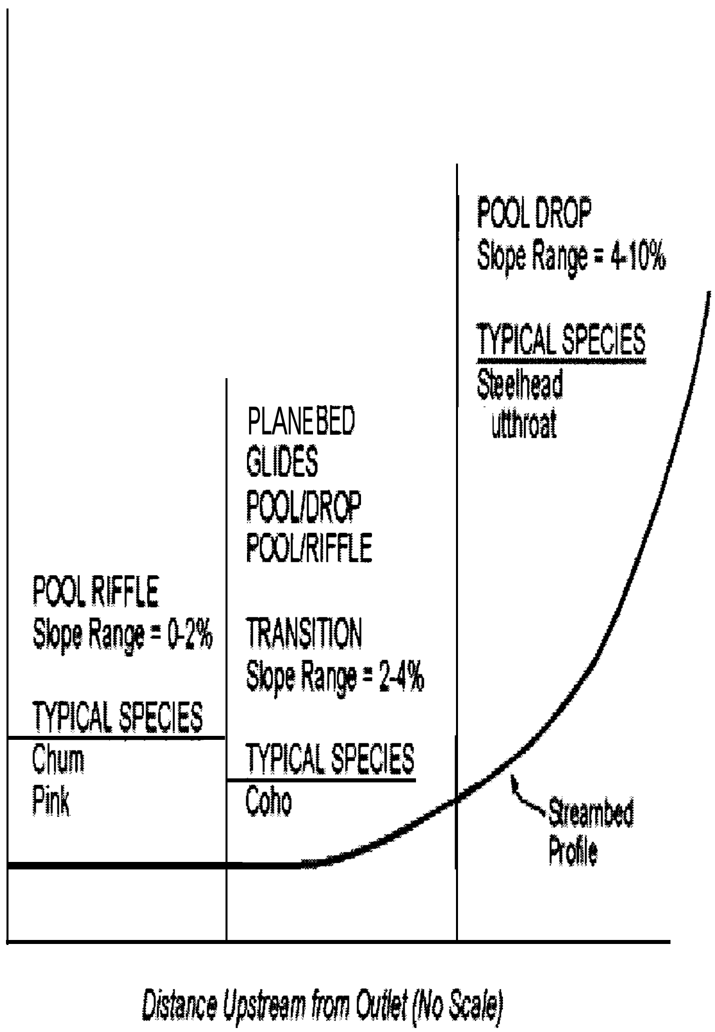

Figure **1.** Relationship of Stream Habitat to Streambed Slope in Western Washington Streams.

Pools and riffles form alternately on the outside of stream bends. These alternating pools and riffles are present in practically all perennial channels. In straight or meandering streams, pools and riffles generally form every 5 to 7 channel widths. As the stream widths increase, however, the number of pools decrease (Leopold, Wolman, Miller, 1964).

In each non-rigid, natural stream, a dominant channel is formed by the **stream=s** dominant discharge. This dominant discharge channel is a component of most fish habitats. The dominant discharge has a recurrence period of approximately once each 1.5 years in natural systems (Simons, Senturk, 1991). In urban systems, the bank-full discharge has a recurrence period of about one year **(MacCrae,** 1996).

Western Washington Natural Stream Characteristics The small streams of western Washington are fed by rain and groundwater and are found in steep-sided canyons with fairly straight valley bottoms. In their natural (forested) state, small streams have a slightly meandering, low-flow channel in a narrow valley bottom. The vegetation along the stream banks is often dense and provides shade, channel stability, and cover. Debris jams are common and act to slow stream flows during storm events. Western Washington soils are products of glacial activity and consist of smooth cobbles and stones, as well as fine materials. Clayey bank materials, heavy root structures along the banks, and steady base flows create channels with nearly vertical sides and small widths (3 to 6 feet wide, and sometimes as small as 1 foot wide) relative to the width of the valley bottom. Typical old-growth forest streams have low nutrient levels and low annual sediment yields.

Most natural Pacific Northwest streams can be described as sediment starved. Natural watersheds are heavily forested and act as a sponge for rainfall. In natural watersheds, the storm runoff response is slow and the flow rates are low. Because the ratio of the 1.5-year storm to the base flow is quite low (often less than 5), these streams have small width to depth ratios, with most of the dominant discharge channel acting as an aquatic habitat channel. The width of the dominant discharge channel is coincident with the width of the aquatic habitat channel. The aquatic habitat channel is the normally wetted, low-flow part of the streambed (Seattle, 1997). Most small, natural Western Washington streams are dominated by pools and drops formed by large organic debris (Gustav, Sovern, Washington, 1993)

The aquatic biological community in western Washington may include as many as 250 plant and animal species. The aquatic biological community depends on a stable aquatic habitat associated with old growth, coniferous watersheds. Much of this aquatic community functions as a food web, with fish populations representing the mega fauna. Some salmon and trout species are the top aquatic predators (Sovern, Washington, 1996).

Salmon and trout in western Washington evolved to take advantage of these regional stream conditions. Figure 1 lists different species found in the various regions of the watershed. More athletic fish species like coho, steelhead, and cutthroat trout occupy the upper reaches (steeper gradient) of the watershed. The young coho and steelhead reside in the stream for a year before migrating to saltwater. Cutthroat may reside in fresh water for two years before migrating to saltwater. Less athletic species, such as chum and pink salmon, can not migrate through the steeper gradients of the upper watershed to spawn. The fry of these species occur in the lower regions of the watershed and migrate to saltwater shortly after emergence. Young salmon, as well as young and adult trout, will utilize any part of the watershed that meets their habitat requirements. For example, if fish habitat in the upper reaches of a watershed is unsuitable, young coho may seek winter refuge in the lower regions of a watershed (Sovern, Washington, 1996).

Five general categories of habitat occur in natural western Washington streams (Sovern, Washington, 1996):

- Estuaries/Deltas
- Passage
- Refuge
- Rearing
- Spawning and Incubation

Pacific Northwest fish derive most of their food from organisms (benthos) that live in, or on, the substrate of the stream. Most food production occurs in the same stream areas that provide spawning and incubation habitat for fish. An annual surplus of approximately 10 pounds of biomass is required to support one pound of fish in the stream (Washington, 1999).

Assessing Stream Deterioration

Visual inspection of stream morphology can provide rapid and relatively accurate assessments of a stream=s ability to support fish populations. Practical experience working in western Washington streams has shown that visual streambed assessments correlate well with benthic sampling (Seattle, 1999). Although benthic sampling is necessary, visual inspections can reduce the amount of benthicsampling required when quickassessments are needed orextensive benthic testing is cost-prohibitive.

Natural streams are generally non-rigid. Their cross-sections vary with changes in flow rates and yearly rainfall volumes. Stream systems will generally aggrade during low flow periods, and degrade during high flow periods. To assess the deterioration of non-rigid streams, it is necessary to understand the following three concepts:

*Sediment transport

*Effects of urbanization on stream stability

*Effects of urbanization on fish habitat

Sediment Transport Concepts Understanding the dynamics of sediment transport is useful for predicting hydraulic equilibrium conditions in a stream. Any stream will respond to imposed changes. Six basic relationships exist between discharge levels and channel form, regardless of stream size (Simons and Sentürk, 1991):

Depth of flow in the dominant discharge channel is directly proportional to discharge.

- Width of the dominant discharge channel is directly proportional to water discharge and sediment discharge.
- Dominant discharge channel shape is directly related to sediment discharge.
- Channel gradient is inversely proportional to water discharge and directly proportional to sediment discharge and grain size.
- Sinuosity is directly proportional to valley gradient and inversely proportional to sediment discharge (larger valley gradient causes greater meander, larger sediment discharge causes less meander).
- Transport of bed materials is directly related to flow velocity and concentration of fine material, and inversely proportional to the fall diameter of the bed material (greater depths and higher velocities cause larger bed load volume in transport, sediments shaped like kites fall slower than round-shaped sediments).

A stable channel exists when a stream has the bed slope and cross-section which allow its channel to transport water and sediment from upstream without aggradation, deposition, or streambank erosion (Simons and Senturk, 1991).

When natural flow rates are exceeded, sedimentation and erosion can be a dominant limiting factor for fish populations. The exaggerated volumes and rates of stormwater runoff in urban areas increase both the rate of erosion and volume of sediments generated from upland and riparian areas in the watershed. Soil erosion can lead to excess streambed erosion and sedimentation and destroy redds, fish rearing habitats, and food production areas.

Effects of Urbanization on Stream Stability Urbanization permanently alters the hydrologic balance within stream in the following ways:

- Total water passing through urban streams increases.
- Stormwater runoff rates and volumes increase.
- Increased impervious surface areas prevent groundwater recharge; as a result, base flow rates during summer and fall are often less than natural flow rates were.
- Increased stormwater runoff causes erosion and transports significant amounts of sediments and pollutants, including oil, grease, and polluted fine sediments from streets and parking lots, into urban streams,

In urban areas, the ratio of the 1 -year storm to the stream=s base flow (dominant discharge) is large, sometimes greater than 100. In many watersheds, terrestrial sediment volumes are dramatically increased by urbanization. Excess sediment increases the width of the dominant discharge channel.

Stable urban streambeds have 182% gradients, compared to the 2810% gradients that support anadromous species in natural watersheds. To reach a stable gradient, the streambed can lower several feet, causing significant bed load sediments from shallow landslides. Measurements taken from several western Washington streams show that streambeds will flatten from a 4% gradient to a 1% gradient as a result of urbanization. A change in streambed gradient from 4% to 1% over the distance of 1,000 feet can result in streambed erosion and an elevation difference of 30 feet at the upper end of the reach. During the transition from steep to flat gradients, fish habitat is in a perpetual state of change (Sovern, Washington, 1996). Unfortunately, it can take decades before stability is again reached.

In unstable streams, braiding occurs at crossover points between bends where stream gradients are steep. At normal stage, a braided section has a divided flow with small, mid-channel bars and a single large channel composed of subordinate channels. The base flow channel often changes location within the bottom of the dominant discharge channel (Sovern, Washington, 1996).

The erosion of the channel bottom along the basin (often called head-cutting) indicates a readjustment of the basin's gradient, the stream discharge, and the sediment load. (Simons and Sentürk, 1991).

Effects of Urbanization on Habitat Stable habitat conditions within the channel have stringent requirements in urban streams, including a sediment-starved condition and minimal movement of spawning-sized gravel (3-inch and smaller) during most storm runoff events.

In urban streams, the benthic system can be limited both by erosion (which provides conditions of constant change) and by sedimentation (which smothers redds and food production areas, and fills rearing habitats with silt). In addition, streams in urban or deforested watersheds experience significant habitat loss and are unable to support the biological diversity that fish species depend upon. In contrast to natural watersheds, where 250 plant and animal species may comprise the aquatic habitat, urban watersheds may have fewer than 50 plant and animal species.

Living systems do not adapt to constantly changing environmental conditions. The changes in aquatic habitats caused by urbanization decrease food production and destroy spawning and incubation areas (Bell, 1990). As flow rates and volumes increase, streambeds become unstable. When streambeds become unstable, the aquatic habitat channel may retain a small width to depth ratio, but it will be substantially less than the width of the dominant discharge channel. In addition, streambed instability causes a constant shifting of the aquatic habitat channel and this limits development of the benthic community and destroys redds.

As an urban stream approaches stability, the resulting aquatic habitat channel will be too wide, shallow, and homogeneous to support fish populations. Streams naturally deposit bed load on the inside of bends and form point bars. Because natural sinuosity is low in western Washington streams, point bars form infrequently or incompletely leaving a wide, shallow, cross section during base flows. Under these conditions, the flow depths of most urban streams are insufficient to submerge returning adult fish. Because small-grained sediments settle as flow rates decrease, redds and food production areas are smothered with silt and pool habitats are filled with sediment.

Perhaps the greatest general impact is the permanent loss of habitat types that sustain coho and steelhead populations. These species prefer pool/drop habitat. Coho, in particular, require quiet pools (Seattle, 1997). Examination of Figure 1 shows that as the streambed gradient lessons, the habitat type shifts from pool/drop to pool/riffle. Pool/riffle habitat does not provide sufficient pool depth for normal fish rearing or urban storm refuge. Because large storms frequently occur after the fry emerge from the streambed gravels, the need for urban storm refuge habitat is critical. Juvenile fish cannot maintain their position in high velocity reaches. In fact, normal urban storm flows often wash juvenile fish into larger bodies of water (salt water or streams) where they cannot survive.

Tools and Methodologies

The methodologies available to assess existing stream conditions and predict future conditions include the use of visual streambed assessments and analytical tools such as simple hydraulic mathematics.

Streambed Assessment

General indicators of habitat degradation in urban streams are visually apparent and include the following elements:

- Dominant discharge channel wider than in natural conditions
- Reduced pool frequency and less diverse habitat
- Increased sediment from terrestrial sources

- Reduced large woody debris
- Drastically reduced aquatic community diversity

Both natural and urban streams fluctuate between stability, degrading, or aggrading. Compared to natural streams, however, streams in urban watersheds exhibit extreme traits of aggradation, degradation, or instability. Urban stream deterioration indicators differ according to the condition of the specific reach (stable, degrading, or aggrading). In a degrading streambed, there is a progressive lowering of the channel due to scour. In an aggrading streambed, there is a progressive buildup or raising of the channel due to sediment deposition. Both degradation and aggradation are indicators that a change in the stream=s discharge and sediment load is taking place (Simons and Senturk, 1991).

Urban stream deterioration indicators differ according to the condition of the specific reach. Table 1 (the following bulleted paragraphs) describes the deterioration indicators in a stable, degrading, or aggrading stream.

Table 1. Urban Stream Deterioration Assessment Indicators

Stable B If an urban stream reach is stable and terrestrial sediment loads are low, the reach may be able to support species that reside temporarily in the stream before moving to salt water. The wide, shallow channel of a stable stream provides little protection from predation, however, and also lacks resting pools. The following are indicators of stable urban streams:

- Apparent changes in channel shape and configuration afler large storms are small.
- Width of aquatic habitat channel coincident with width of dominant discharge channel B shallow flow depth, prevents fish passage.
- Head-cutting and nick points are absent or nearly absent.
- Substrate stability:
  - Periphyton stays on streambed after significant storms B streambed is stable.
  - Streambed gravel lack periphyton B gravel is being moved during significant runoff and replaced when the storm flow recedes,
  - Small-grained sediments settle when storm flows recede, smothering redds and food production areas.
  - Pools (on-stream or off-stream) that can retain newly hatched fry are generally not present.

Degrading B In a degrading urban stream the dominant discharge channel is as wide as in a stable stream, but base flow rarely covers the bottom of the channel except at crossover points between bends. When streams begin to unravel due to degradation, the effects do not appear instantly. Head-cuts move through a stream until it reaches a vertical drop. When enough head-cuts accumulate, the vertical drop will be undercut, releasing large amounts of bed load type sediments. Occasional pools will develop that may support anadromous fish, however, they are often inaccessible.

- Streambed gravel sizes are larger than stable sections of the stream, but are mostly bare of periphyton or other aquatic growth.
- Channel braiding occurs at crossovers between bends.
- The substrate of the base flow channel is not coated with periphyton.
- The base flow channel and dominant discharge channel lack large woody debris.
- Large woody debris that spans the banks of the dominant discharge channel may indicate a recent streambed elevation and may illustrate the amount of degradation that has occurred.
- Stream banks are bare and often nearly vertical.

Aggrading B Aggrading stream reaches may be visually similar to stable reaches. Generally, aggrading streams will have a flatter streambed gradient and accumulate more fine sediment. Disturbing the bed of an aggrading reach usually results in long periods of murky water flow. Aggradation will occur locally in pools, which reduces habitat value, but has less impact on habitat than an entire aggrading stream reach would.

- Head-cuts and nick points do not exist.
- Deltas may be visible at the top of the reach.
- Periphyton covers the substrate.
- Large woody debris in streambed is partially buried.
- Pool/riffle and pool/drop habitat can occur as isolated conditions.
- Substrate surface gravel sizes are small.

The visual indicators described in Table 1 (combined with assessments of fish passage problems and periodic benthic population checks) can be used to describe the potential habitat capacity for a stream reach or, collectively, for an entire stream. Needless to say, habitats for fish species that reside in the stream for one year or longer must be able to support the full life cycle of the species. In addition, fish need to have full access to these habitats.

A methodology based on visual streambed assessment was developed for rapid stream assessments in Longfellow Creek and Pipers Creek in Seattle, Washington (it was also used within six watersheds in Snohomish County, Washington). The streambed assessments provided an accurate measurement of the ability of the watershed or stream in question to support fish. An example of the summary rating for Longfellow Creek is shown in Table 2.

Table 2. Summary Rating for Longfellow Creek

Creek Segment	Description	Map Sheet	Habitat'	Bank Erosion'	Sediments Sources*	Other Pollutants*	Total
1	Pipe from outfall to Andover Street	1,2,3	5	3	3	2	13
2	Open channel from Andover Street to Genessee Street	4,5	10	1	1	2	14
3	Open channel from Genessee Street to confluence of unnamed tributary in West Seattle Golf Course	5,6,7	10	2	2	2	16
4	Unnamed tributary in West Seattle Golf Course	6,7	6	2	2	2	12
5	Open channel from confluence with West Seattle Golf Course tributary to Brandon Street	7,8,9	9	1	1	2	13
6	Open channel from Brandon Street to Findlay Street. Contains confluence of Juneau Street bypass via "biochannel."	9	9	2	2	2	15
7	Open channel from Findlay Street to Juneau Street. Also contains piped high flow bypass starting at Juneau Street and rejoining Creek in Segment 6.	9,10	8	2	2	2	14
8	Open channel from Juneau Street to Graham Street	10,11	11	2	3	2	18
9	Open channel from Graham Street to Willow Street	11,12	8	2	1	2	13
10	Open channel from Willow Street to Myrtle Street	12,13	8	2	2	2	14
11	Piped channel Webster Basin; open channel to Holden Street. Contains "K-Mart bypass."	13,14	7	2	2	2	13
12	Open channel from Holden Street to Thistle Street	14,15,16	8	2	1	2	13
13	Pipe from Thistle Street to head of basin at Roxbury Street	16	6	3	1	2	12

Notes:

Ranking Codes:

1 = Poor condition
2 = Moderate
3 = Relatively good

• ■ The value in the "habitat" column is the result of another ranking process. The total "habitat" volume for each Creek segment is transferred into this table to complete the ranking process. The habitat rank has a range of O-18 which is developed from evaluating bed erosion, fine sediment accumulation, gravels (clean/stable), benthic (quantity, quality), habitat structure, and riparian vegetation. All other columns in this table are ranked from 1 (poor condition) to 3 (relatively good condition).

Analytical Tools Simple hydraulic mathematical tools can be applied to analyze existing conditions and are needed to check passage conditions for channel rehabilitation projects. In addition to depth and velocity, the amount of turbulence in a stream has significant impact on the amount of sediment that can be moved. Greater turbulence increases the amount and size of sediments that can be moved. Maximum turbulence occurs when the Froude number is equal to 1 .O. The Froude number is defined by Equation 1:

$$F_N = V/(gY)^{1/2} \qquad \text{(Equation 1)}$$

Where

F_N = Froude number

V = average velocity in the cross-section

g = acceleration force due to gravity

Y = the hydraulic depth, which is the cross-sectional area divided by the top width

The Froude number should not exceed 0.8 for large storms (like the 25 or 100-year event) except at channel drops. This criterion is the same for rigid, grass, and dirt lined channels in most stormwater manuals. For frequently occurring storm flows (1 to 2 year events), the Froude number has to be much less in order to meet the criteria for larger flows. Spawning-size gravel will generally be stable if this Froude number criterion is met.

In the author's experience, backwater analysis (HEC-2 or HEC-RAS) may not be strictly applicable to analyze natural streams, but is a useful tool to analyze deteriorated channels and to model proposed improvements for stream rehabilitation. For stream rehabilitation backwater analysis is done for large and small events (base flow, 1 -year flow, and one point in between) to ensure passage of juveniles throughout their life-cycle habitat within the stream. To provide accurate results, more cross-sections are needed to conduct backwater analysis on non-rigid, urban streams compared to conventional backwater analysis.

Selecting Rehabilitation Devices

Unless excess stormwater from both frequent and rare storm runoff events can be eliminated, it is the author=s opinion that some form of structural intervention is needed to create fish habitat in urban streams. In western Washington, streams become unstable and significant fish habitat is lost when the impervious area reaches 10 to 15 percent (Booth, 1996). The dominant discharge channel will respond to hydrologicchanges (Simons and Senturk, 1991). As a result, modifying how land is urbanized can reduce the effects of urbanization, but it will not obviate the hydraulic impact on the dominant discharge channel. Stream rehabilitation measures will still work best where there are fewer disturbances to the watershed and where wide riparian corridors are maintained.

The goal of urban stream rehabilitation is to stabilize the streambed with devices that also create a habitat for fish populations. The stream must develop sufficient food mass and diversity to support desired fish species. Quality salmon and trout habitat can exist in urban streams when hydraulic/habitat criteria are met, the streambed is stable, and the base flow channel is confined (Sovern and Washington, 1996).

Establishing stable streams in urban watersheds is often a moving target. As more urbanization occurs, hydrologic and biological changes accumulate. The extent that the dominant discharge channel spreads is a direct function of the amount of pavement in a watershed.

The New Urban Stream. Restoring an urban stream to pre-development conditions is not possible (National Research Council, 1992). It is the author's opinion that too many stream rehabilitation projects emphasize stream bank rehabilitation rather than focusing on the root causes of stream habitat destruction. Often, that root cause is streambed instability, which is a natural response to increased flow rates and volumes in the stream.

To maintain pre-development species in urban and deforested streams, a "new urban stream" is needed that can provide a variety of fish habitats including pools. Without intervention, the urban streams will convert pool/drop habitat into pool/riffle habitat, eliminating the diversity of habitat required to support a variety of fish species (Sovern and Washington, 1996).

The goal is to stabilize the stream and return it to its original sediment-starved condition. While bed load and suspended sediment are readily available, the object is to sculpt sediment deposition to form bars and banks and confine the aquatic habitat channel within a single location. Concentrating flows in the aquatic habitat channel helps keep the substrate size optimal and clears the stream of fines.

Urban stream rehabilitation must focus on historic conditions that can be recreated, rather than on the conditions that cannot be meaningfully restored. Except for the following three exceptions, historic environmental conditions can be recreated in urban streams:

- The width of the dominant discharge channel will always be greater in urban streams.
- The banks of the aquatic habitat channel cannot be coincident with the dominant discharge channel (in pool/riffle habitat).
- High flood flows, deep flow depths, and large velocities are more frequent.

In form, the resulting channels resemble snowmelt type streams, where flow rates significantly exceed base flows for several weeks each year. Most urban streams lack large woody debris that can be incorporated into the stream's structure when a reach attains stability. Most reaches will take decades to reach stability. Just because the channel will not look "natural", doesn't mean that we will have failed or that anadromous species cannot be supported. Many eastern Washington snowmelt type streams support anadromous species.

A rehabilitated stream has five primary needs:

- A dominant discharge channel sized to carry the 1 -year to 1 S-year storm (depending on the degree of urbanization) at full bank. It is important to recognize this need because the stream will reshape the dominant discharge channel and may undo much of the rehabilitation effort.
- Within the dominant discharge channel, hydraulic conditions must provide biologic and stream stability (keep most of the spawning sized gravel and rock from moving during frequent storms).
- Within the dominant discharge channel, habitat must be provided for the entire life cycle of the desired species.
- Because fine-grained sediment falls out last and needs to be kept in transport, the base flow channel has to be narrow, deep, and stable.
- Stream banks need to be stable to support riparian vegetation. Bio-stabilization techniques can help reduce the width of the dominant discharge channel.

Ideally, long reaches of unstable streams will be stabilized. Near the spanning structures, aggradation will replace degradation (as long as a sediment supply is available). If only short reaches are stabilized, large storms will deposit substantial sediments within the stabilized reach, particularly at the upstream end of the reach. The sediment sizes most likely to accumulate during the stabilization of a reach are the larger sizes that are moved as bed load. Once stable streambed gradients are attained, the amount of sediment that can move and cause aggradation is finite. After a few larger storms, bed load movement will be minimal.

Rehabilitation Devices A variety of devices may be used to confine the base flow channel and provide streambed stability. The author has experience with several types of bed control structures, glides, lunkers, and confining devices. In small streams, these devices may be a well-placed piece of timber, a boulder, or randomly placed stones and rootwads (to increase roughness). In larger streams, stabilization and confining devices are much more complex.

Selection and siting of devices is dependent on the stream condition in a specific area and the type of habitat that is to be provided. It is important to realize that one type of structure is not suitable for all applications. Selection of a stream rehabilitation device depends on the type of habitat needed and the device's perceived hydraulic attributes. Both non-rigid channel design and biologic skills are required to be successful.

This section will address issues related to the selection of three types of structures: timber stepdown structures, boulder bed control structures, and deflectors.

Timber *Stepdown stepdown*. Sometimes referred to as a "K-structure". A form of timber is shown in Figure 2. The logs, which are set at 45 degrees to the channel, are called weir logs and create pools during high storm flows. The weir logs need to have a steep pitch (the bank end higher than the center of the stream). In dense, urban western Washington watersheds, storms with high yearly return frequencies produce flows 20 to 50 times the base flow. Timber stepdown structures form large, quiet pools during storms, allowing newly emerged fish juveniles to find refuge. In

Figure 2. Timber Stepdown K-Structure (shown with weir logs).

addition, the K-type stepdown creates rollers. Rollers assist fish passage upstream for less athletic adults and juveniles during higher flow rates (Kerr Wood Leidal Associates, LTD, 1980).

Common variations of the K-structure include a straight timber stepdown (no weir logs) and a vortex structure (with weir logs). In creating a diverse habitat environment, both types can be used.

While the straight timberstepdown does not form an upstream pool, the substrate above the stepdown is turned-over, even for frequently occurring storm flows. The Washington Department of Fisheries and Wildlife has successfully installed many straight timber stepdowns in logged watersheds and those with minimum to moderate urbanization. For lower flow rates, the substrate above the stepdown remains stable and provides excellent spawning habitat.

The vortex type timber stepdown does not form storm refuge pools as well as the k-structure and the log configuration stymies formation of a roller. The structure can help develop confined low flows, however, and creates good fish-rearing habitat for many northwest species (not Coho).

Boulder *Bed* Control Structure. Figure 3 shows a boulder bed control structure. Like the K-structure, the boulders that form the structure are on the upstream side, but these boulders could also be on the downstream side to form a vortex-type structure. In the author's experience, changing the configuration and the angles of the boulders provides slightly different habitat characters, all of which are acceptable. While wood is usually preferred in small streams, boulder bed control structures are flexible and can adjust to channel degradation in unstable streams. Boulder bed control structures are most beneficial at the downstream end of a reach where no streambed control is established in the reach below.

Deflectors. Deflectors can be made of either wood or boulders. Figure 4 shows a timber deflector with a bank log on the opposite bank. Point bars form on the insides of bends. Deflectors should be installed on the insides of bends to help build larger point bars and to confine the base flow channel. The reach in Figure 4 is nearly straight (sinuosity about 1 .O). To develop point bars in straight reaches, several deflectors may be needed and could be on one side of the channel, or on alternating sides. The reach shown in Figure 4 has a large bed load, and point bar formation would have occurred if the deflector installations were correctly located and implemented. Without modification, however, the deflector shown in Figure 4 will not form a point bar.

Figure 3. Boulder Bed Control Structure.

Figure 4. Deflector.

Conclusions

Streambed assessment based on sediment transport principles can be a useful tool to rapidly determine a stream's capability to support fish populations. Standard engineering analytical tools can be used with streambed assessment to support hydraulic design for stream rehabilitation projects. Although the stream will not have the same appearance as a natural stream, stream rehabilitation can be successful and urban streams can support anadromous fish populations in western Washington. Hydraulic design is needed to develop the dominant discharge channel and properly place structures to attain the desired habitat conditions. Selection of the rehabilitation devices must consider design needs of non-rigid channels, as well as habitat requirements. Finally, one size or type of habitat rehabilitation device cannot serve all purposes. Selection of habitat rehabilitation devices should achieve specific habitat requirements and provide habitat diversity.

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